Changing City – Changing Flood

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Abstract

Reliable and precise information about possible floods, related water levels and inundation areas are needed even in urban areas to minimize potential damages. An important requirement for this issue is to adapt the stage-discharge relations to the changing constraints which could arise from morphology and hydrology. This paper reconsiders the use of historical hydrologic data in urban areas which have fundamentally changed even concerning the river beds, cross sections and floodplain areas. By means of a historical approach the flood statistics have been updated with surprising results.

Introduction

Vulnerability and Resilience of communities against floods have changed during the centuries. Very often also the river banks and river beds in urban areas were reshaped in the past so that stage-discharge curves were and are valid only for certain periods. These changes have to be considered when evaluating flood statistics.

Figure 1. left: glimpses of the river situation through the history – changing city on the changing river. right: Elbe river in Dresden: top 1845 before the big river training measures, bottom 2002

Reliable flood records from the past are a precondition for the prediction of future developments. Only on the basis of proved statistics it is possible to extrapolate e.g. trends due to non-steady constraints. But often even the past records are uncertain or wrong. In this context historical flood records are an important source when estimating the flood statistics at a river gauge. The statistical evaluation of flood records requires long data series to extrapolate reliable peak discharges and related recurrence intervals. But the historical flood information often refers only to the water levels because the methods of velocity or discharge measurements had been developed only later. As the distribution functions are usually fitted to the discharge values historic stage-discharge-relations must be found to convert the stage

values to discharge values.
As long as the mankind can remember, people have built their settlements near rivers. Thus they could take advantage concerning water supply, hydropower generation, fertile soils, agricultural irrigation, transport of goods and navigation respectively. But settling near the river has also one main disadvantage: the hazard of inundation.
Appropriate stage-discharge-relations for rivers in urban areas are important for protecting the people, for a reliable flood forecast as well as for identifying the right flood protection objectives. These rating curves are subjected to long-term changes due to the natural bed load transport and human activities.
Against this background a more detailed analysis at many gauges shows that the stage-discharge-relation sometimes seems to be not correct [4]. For instance at the Dresden gauge for the 1845 flood the official peak discharge is 5700 m³/s at a stage of 877 cm above the gauge datum whilst 2002 the flow rate should have been 4581 m³/s at a stage of 940 cm (ADCP measurement)[8]. To clarify this and other discrepancies the author had proposed to run water profile calculations with historical data sets. This has e.g. been carried out up to now for two historical flood events at the Elbe river in 1845 [8] by means of one-and two-dimensional models (HEC-RAS, Hydro_AS-2D and 1890 [1] within a RIMAX-Project).

Data Sources

For the Elbe River at the Dresden gauge as well as some other gauges historic flood descriptions have been handed down for more than 1000 years. The oldest flood events were only described from the viewpoint of damages. Discharge data are almost always missing. Due to the exceptional character of extreme flood events which happened only once in one's lifetime the chroniclers sometime tended to overstate. The handed down water level data can be inexact and often it does not fit into the present reference system. Reliable stage data can be derived from flood marks at historical buildings. Here it must be ensured that the marks are at their original place. This is guaranteed best when they are carved in a natural stone building front or column. Due to possible inaccuracy and missing reliability appropriate care has to be taken when using historical data (s.a. [5]).
Quantitative information are available (with gaps) since 1501. The systematic water level recording started at the Dresden gauge in 1776 [6] and the discharges have been documented since 1806 (catchment area 53096 km², mean discharge 324 m³/s, today Elbe-km 55.600). Referring to this data the history of the water course and its morphology was investigated.
For some tributaries at Dresden the series of records covers 300 years and more. But in the urban areas the flow conditions have been changed due to human activities. Referring to the available data the history of the water course and its morphology has been investigated. Using the former flow cross sections water profile calculations were carried out yielding different stage-discharge-curves for each historic period.
To establish a historical digital terrain model for 1845 (and other points in time) the historical Elbe river map from 1850/55 (scale 1:12000) was used (Fig. 2 [7]). Herein not only the cross sections but also the water stages and inundation areas during the 1845 flood had been drawn. Additional required but missing quantities were measured in or interpolated from the map.

Extraordinary Floods

One of the three most severe floods in Dresden was the winter flood on 31st March 1845. Fig. 2 shows the wide area inundation in the city of Dresden. Sudden thawing of a 1.50 m thick ice cover on 27th March caused an ice break-up with ice jam upstream the Dresden Elbe Bridge (today Augustus bridge). On 29th March a large part of the historic city of Dresden was inundated, which has been mapped on historical maps. Many people had to be rescued

through the windows by means of boats. Major damages occurred. Also the only Elbe bridge at that time was damaged and the crucifix pier broke down.
The highest water level of the Elbe within living memory was measured on 17th August 2002 during a summer flood. Although the water level was higher than in 1845 less area of the city was inundated as Fig. 2 indicates. This is due to changes of the cross section and to the rise of the ground elevation in the city. Just 5 days before the city centre was inundated by the tributaries of the Elbe which cross the urban area of the upper Elbe valley flowing towards the Elbe river. Due to the smaller watersheds they have a short concentration time to peak of only few hours.

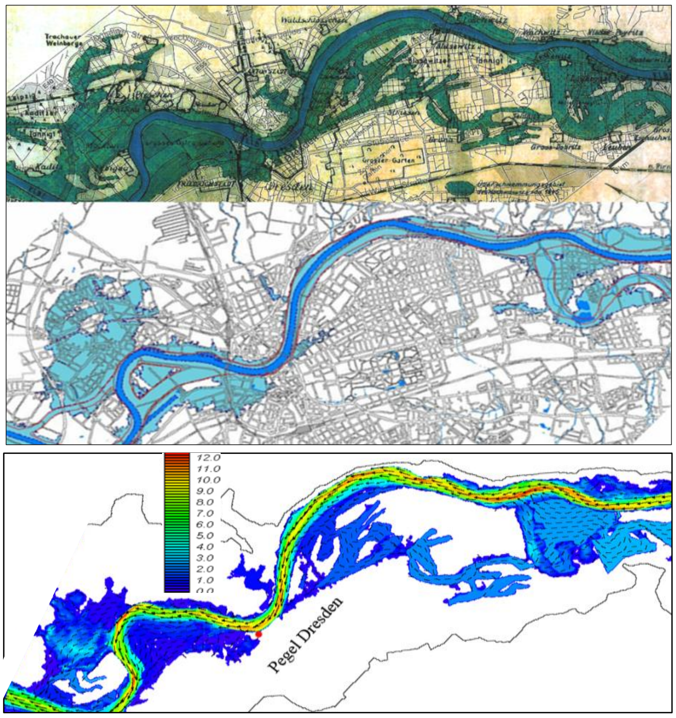

Figure 2: Inundation map of the Elbe river in the city of Dresden: top 1845, centre 2002 (www.dresden.de), bottom hydronumerical calculation with a 1845 digital terrain model

HN Profile Calculations for historical Situations

Using the former flow cross sections water profile calculations with 1D and 2D models have been run.
The cross section profiles were adapted from the sections in the old Elbe river map that were referring to the navigable water level. Beyond the mean water channel the ground elevation data were completed with elevation data derived from maps and DTMs taking into account the former development and land use.
Comparing the historical and the today's map it is obvious that the width of the Elbe until the middle of the 19th century was about twice compared to the today's width (Fig. 1). This is due to the river training for better navigability beginning in the second half of the 19th century. However the deepening due to erosion was less than expected and amounts only between 0 and 60 cm.
By means of hydronumerical models a stage-discharge-relation for that time had been found which was used to convert the water level of the flood of 31.03.1845 to a discharge value. The calculated profile stretched from Pillnitz to Gohlis (both suburbs belonging to the city of Dresden). The lower boundary condition was the normal depth at a longitudinal slope of about 0.025 %. The distance between the cross sections refers to today's stationing.

The bridge afflux at the old bridge is visible in Fig. 3. This appears at discharges greater than some 2000 m³/s.

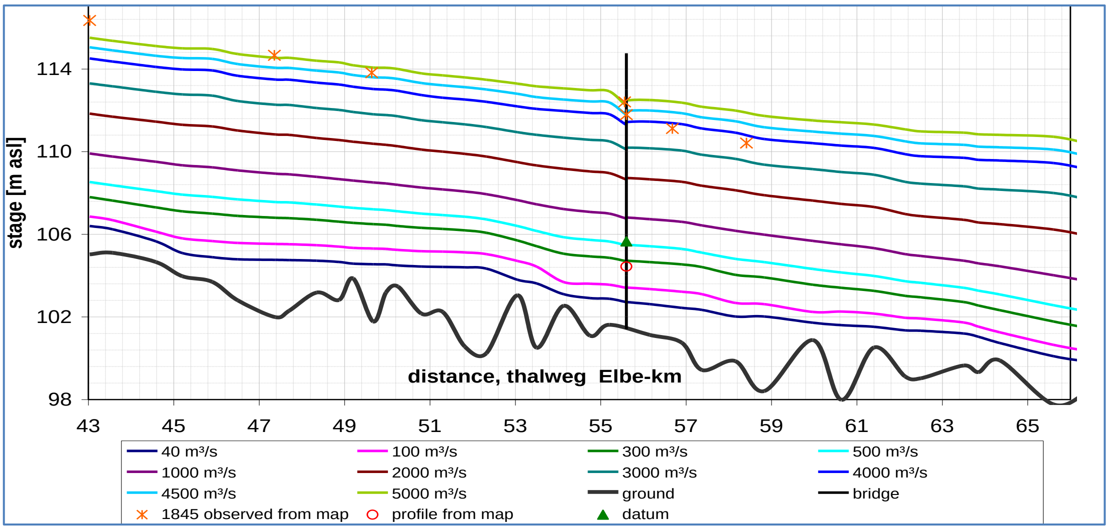

Figure 3: calculated profiles with the bed morphology of 1845 for several discharges at n = 0,035 s/m$^{1/3}$ from Elbe-km 50,25 to 60,64. reference level for the cross sections = navigable water level 2°3“ below old gauge datum.

The above mentioned profile calculations were also carried out for other definite points in time with its respective morphologic situations such as 1890, 1940, 2002, 2006. Strictly speaking for every year an individual stage-discharge-relation (rating curve) is required to yield discharge values from the handed down stage records. Between these nodes the flow rates were interpolated by using both the curve at the beginning and at the end of the period in which the actual value occurs. Depending on the position of the actual year in the period a weighted mean from the flow rate at the beginning and at the end was calculated. Before 1845 the flow cross sections were assumed to be approximately constant for the time being. Therefore the stage-discharge-curve of 1845 was also applied for the floods before.

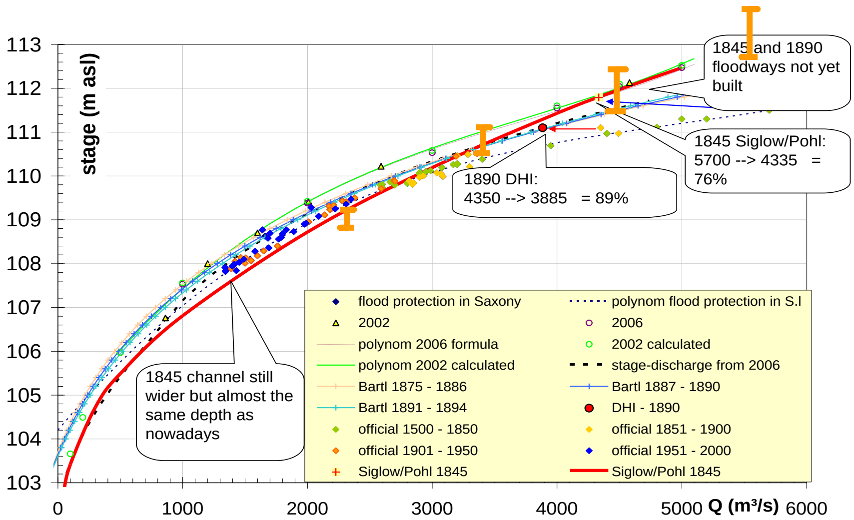

Figure 4: comparison of the stage-discharge-relations at the Dresden gauge

The checked stage-discharge-curves given by different authors and methods mark a band in the diagram (Fig. 4). A sensitivity check yields that the spread is almost not wider than due to the variation of the possible roughness. Beyond 3000 m³/s the official values up to now are noticeable greater than the average of the re-evaluated curves and probably overestimate the true peak discharge values.

Updating Hydrology

Due to the new stage-discharge-relations the flow rates greater than some 3000 m³/s had to be reduced and values below about 2000 m³/s had to be increased. With the corrected discharge values a new statistical evaluation has been done by means of the program HQ-EX by DHI-WASY. It becomes visible that the 2002 flood with a peak discharge of 4581 m³/s was less frequent than originally assumed. Instead of 150 years the recurrence period now is some 500 years (Fig. 6).

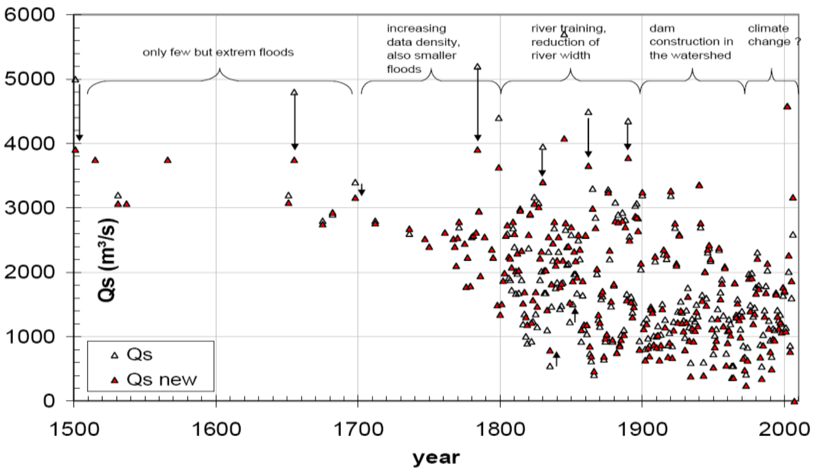

Figure 5. Floods of the Elbe river in Dresden since 1501 A.D. – hollow triangles mark the "official" peak discharges up to now, filled triangles mark the revised values

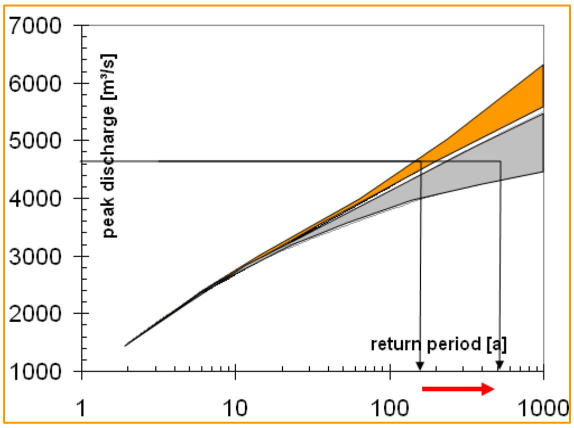

Figure 6: comparison of the extrapolated flow rate before (top) and after (bottom) the reevaluation of stage-discharge-curves at the Dresden gauge

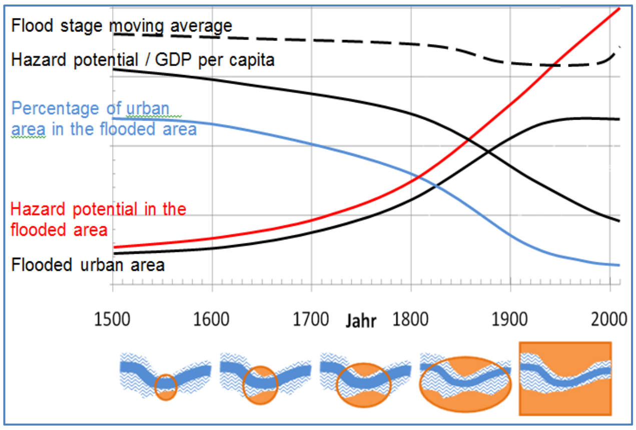

Figure 7: Qualitative description of the estimated consequences of extreme floods with schematic map of the inundated area of the city.

Conclusion and Outlook

The above considerations show that a check of the stage-discharge-curves of the past should be done by means of water level calculations with historical data if the availability of geographic and stage data allows it. The result is a stage-discharge-relation being valid for a year or a certain time period. After converting the peak stages to peak discharges a probability distribution function can be fitted to the values in order to extrapolate the new return (recurrence) periods. The example of the Dresden gauge shows that as a result of this investigation the design floods can change.

The above investigations assume steady hydrologic conditions. At the Dresden gauge no tendency towards increasing peak discharges could be shown to be significant. If such trends due to climate change or other causes should become evident the return periods and the degree of protection will have to be adjusted.

Densely populated urban areas at rivers are often exposed to flood risk. In many cases they can be inundated from both sides: from a main river with the large catchment area which coming hydrograph can be forecasted for more than one day due to upstream gauging and the city-crossing streams from smaller watersheds which have a so short concentration time to peak that makes a reliable flood forecast impossible in most cases. To improve the flood protection even for the smaller catchment areas with high damage potential an ERA-NET Crue project has been established: The project SUFRI (Sustainable Strategies of Urban Flood Risk management with non-structural measures to cope with the residual risk) aspires to an improvement of flood risk management in case of disaster flood especially in respect of non-structural measures. Flood analyses have shown that structural measures of flood protection are limited applicable, especially in urban areas, and that an absolute protection is not feasible. Beyond this research program it is planned to investigate the resilience of people at flood risk.

This will include the estimation of the relative per capita damages with respect to the gross national product (GNP) per capita in those years and nowadays.

For the case study area it seems that the general vulnerability has been decreasing as it could be found by means of characteristic indices. Also the relative values of inundation and hazard seem to become smaller. In other parts of the world (especially with a huge growth of population in coastal and fluvial areas) other tendencies than in Fig. 7 might to be expected and are worth to be investigated.

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